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MASS SPECTRAL FRAGMENTATION OF VX

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14. ABSTRACT

The objective of this study was to provide structural identification of VX fragment ions formed during mass spectrometric analysis, elucidation of fragmentation pathways, and a compilation of tandem mass spectral product ion spectra to aid in detection and confirmation of trace levels of VX in complex matrices. Fragmentation was observed and is reported here for both electron ionization and chemical ionization (methane) conditions. Isotopic labeling analysis using d_5-VX was performed to provide confirmation of selected structural assignments, particularly for the m/z 139 ion for which two structures have been proposed in the literature.

15. SUBJECT TERMS

Mass spectrometry	Chemical ionization	Fragmentation pathway
Electron ionization	VX	Collision-induced dissociation

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PREFACE

The work described in this report was started and completed in February 2000.

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MASS SPECTRAL FRAGMENTATION OF VX

1. INTRODUCTION

Detection and identification of chemical warfare (CW) agents is important for monitoring the future destruction of chemical stockpiles, environmental cleanup of past storage sites, and allegations of CW agent use as prohibited by the Chemical Weapons Convention.[1] Detection of O-ethyl S-[2-diisopropylamino)ethyl] methylphosphonothiolate (VX) at low levels (ppb) by electron ionization/mass spectrometry (EI/MS) is especially difficult because extensive fragmentation occurs. The application of EI and chemical ionization (CI) mass spectrometry for the analysis of VX has been previously reported.[2,3] Tandem mass spectrometry (MS/MS) has been identified as a potential method that provides the sensitivity and selectivity via matrix elimination to make low level VX detection feasible and provides an additional verification method for treaty analysis.[4] Bell and coworkers have reported the use of tandem mass spectrometry to elucidate VX fragmentation under electrospray ionization conditions.[5] The objective of this study was to provide elucidation of fragmentation pathways and structural identification of VX fragment ions formed under EI and CI conditions, and to provide a compilation of MS/MS product ion spectra to aid in detection and confirmation of trace levels of VX in complex matrices in future efforts.

2. EXPERIMENTAL PROCEDURES

2.1 Materials

The Chemical Agent Standard Analytical Reference Material (CASARM) program provided the VX as lot VX-U-2128-CTF-N (vial 187). The gas chromatography/mass spectrometry (GC/MS) purity was 94.6%. The d_5-VX, containing deuterium atoms on the ethyl group, was synthesized in-house.

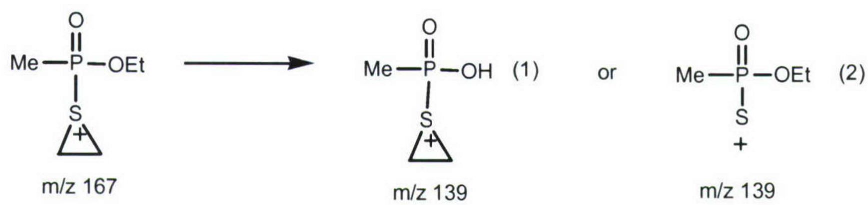
2.2 Instrumentation

Product ion spectra of VX and d_5-VX were obtained using a Finnigan (ThermoQuest, San Jose, CA) TSQ-7000 triple-stage quadrupole mass spectrometer equipped with a 30m x 0.25mm DB-5 column (J&W Scientific, Folsum, CA). Helium carrier gas flow was 1 cc/min, injection temperature 250 °C, interface temperature 250 °C, manifold temperature 70 °C, source temperature 150 °C, and oven temperature 60-270 °C at 15 °C/min with a 5-min hold at 270 °C. The electron energies and emission currents were 70 eV and 400 μA for EI and 200 eV and 300 μA for CI, respectively. Methane was used as the CI reagent gas at a pressure of 3500 mTorr. All collision-induced dissociation (CID) MS/MS experiments were performed using Argon as the collision gas with a collision pressure of 1.5 mT and collision energy of 15V.

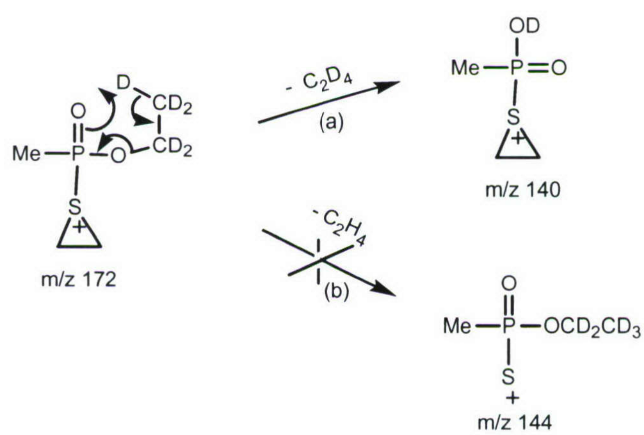
3. RESULTS AND DISCUSSION

The EI and methane CI mass spectra for VX and d_5-VX are provided in Figures 1 and 2. Proposed structures for each ion based on MS/MS fragmentation data are listed in the Table. An overall scheme of proposed VX fragmentation pathways consistent with MS/MS data is provided in the Scheme. Although listed as originating from a neutral VX molecule, fragmentation can occur either from neutral VX (m/z 267) or protonated VX (m/z 268), depending upon whether electron or chemical ionization is used. Tandem MS product ion spectra for each ion are provided in Figures 3-22. Spectra are labeled to identify the mode of analysis (EI and CI). In cases where the same mass ion was subjected to CID analysis under both EI and CI conditions, similar product ion spectra were obtained.

Isotopic labeling using VX labeled with deuterium on the ethyl group was used to conclusively identify the ion at m/z 139. The full scan EI mass spectrum of VX-d_5 (Figure 1) shows that the m/z 167 ion is shifted to m/z 172, indicating the d_5-ethyl group is still intact and providing support for the proposed structure of this fragment. The m/z 137 ion can potentially be formed from the m/z 167 ion by two pathways, via elimination of ethylene from either the O-ethyl group or from the sulfonium ion group.

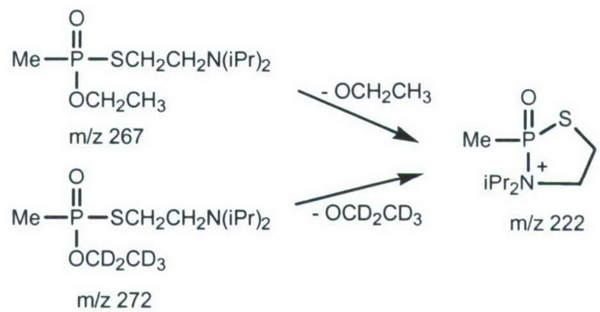


The most logical route is the formation of fragment 1 due to the expected sulfonium ion stabilization of the positive charge. This route is indeed confirmed, as the EI spectrum of the labeled compound shows the m/z 139 ion is shifted to m/z 140 as expected from mechanism a and not m/z 144 as would be expected from mechanism b shown below. The observed mechanism of formation using VX-d_5 is shown as follows:

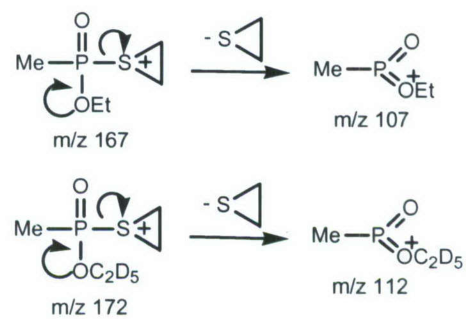


Comparison of the EI and CI Spectra of d_5-VX and unlabelled VX also provides support for other proposed fragment identifications. The data indicates the ethyl group is intact

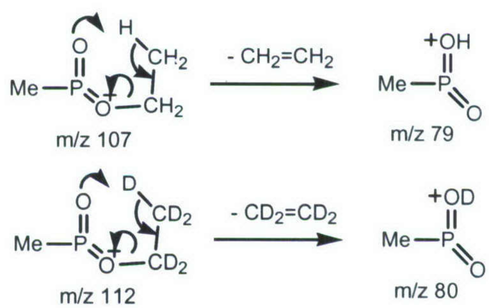
in the fragment ions at m/z 252 and 224 (m/z 257 and 229 in the d_5-VX spectra). The ion at m/z 222 appears in both unlabeled and labeled spectra, consistent with the proposed formation from loss of the O-ethyl group as follows:



The ion at m/z 107 in the unlabeled EI spectrum is shifted to m/z 112 in the labeled EI spectrum, consistent with the following pathway and structure assignments:



The observation that the ion observed at m/z 79 in the unlabeled EI spectrum is shifted to m/z 80 in the labeled spectrum is consistent with the following mechanism:



In addition, it was observed that m/z 97 was formed as a product ion during CID fragmentation of the m/z 79 ion. As proposed by Bell and coworkers,[5] formation of this ion can logically be explained as reaction of the m/z 79 ion with trace levels of water:

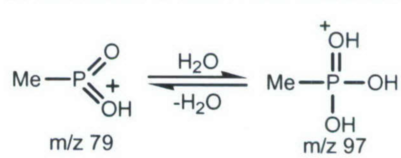


Table. Proposed Structures of VX Mass Spectral Fragmentation Ions

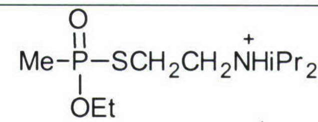
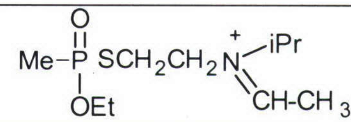
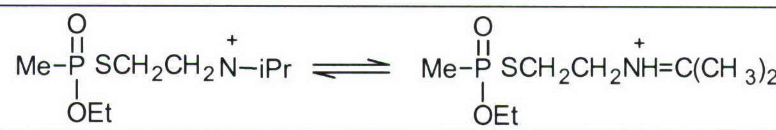
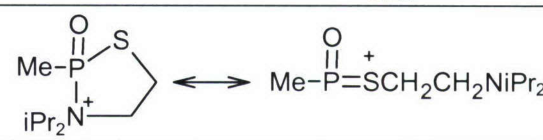
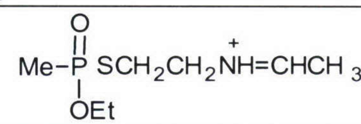
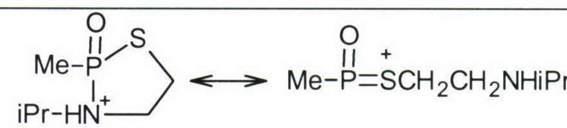
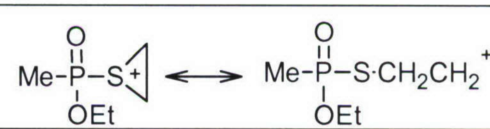
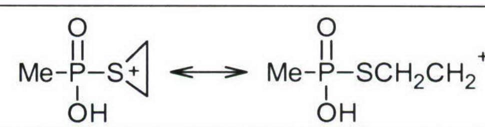
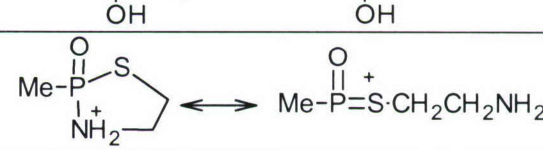
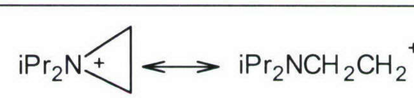
M/z	Proposed Structure
268	
252	
224	
222	
210	
180	
167	
160	$iPr_2\overset{+}{N}HC_2H_3S$
144	$CH_3\text{-}CH{=}\overset{iPr}{\overset{+}{N}}C_2H_3S$
139	
138	
128	
127	$[CH_2{=}CHN(iPr)_2]^{+\cdot}$

Table. Proposed Structures of VX Mass Spectral Fragmentation Ions (Continued)

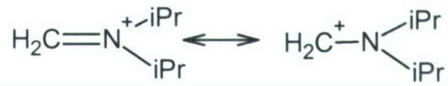
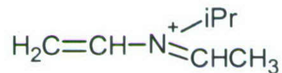
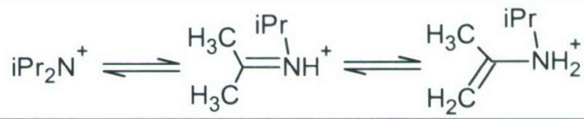
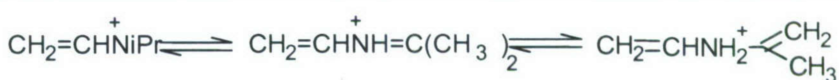
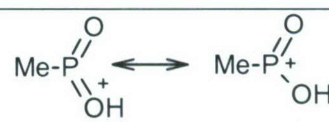
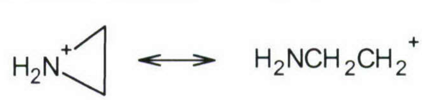
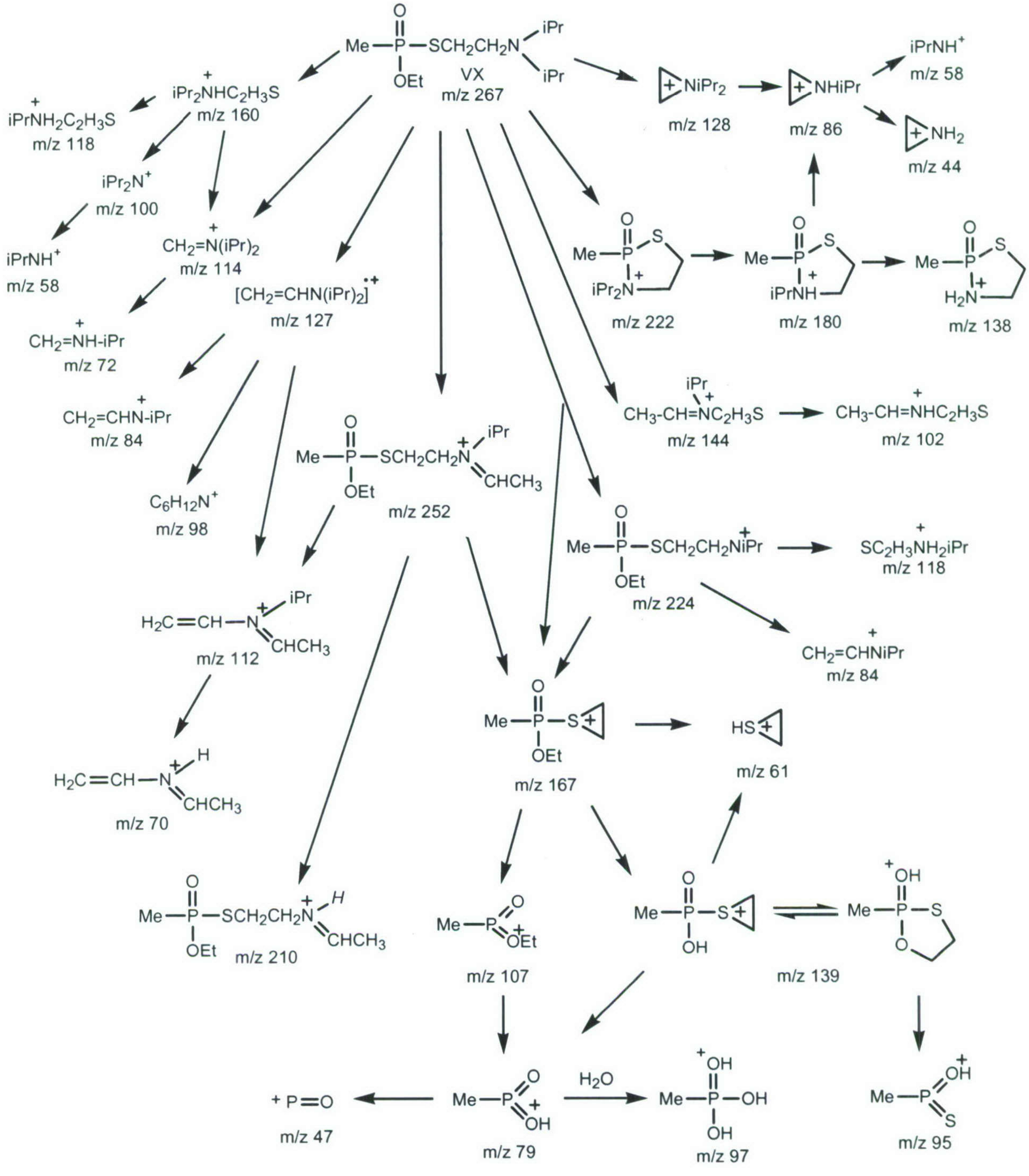
M/z	Proposed Structure
118	$iPr\overset{+}{N}H_2C_2H_3S$
114	
112	
107	
102	$CH_3\text{-}CH{=}\overset{+}{N}HC_2H_3S$
100	
98	$[C_6H_{12}N]^+$
95	
86	
84	
83	$[C_5H_9N]^{+\cdot}$
79	

Table. Proposed Structures of VX Mass Spectral Fragmentation Ions (Continued)

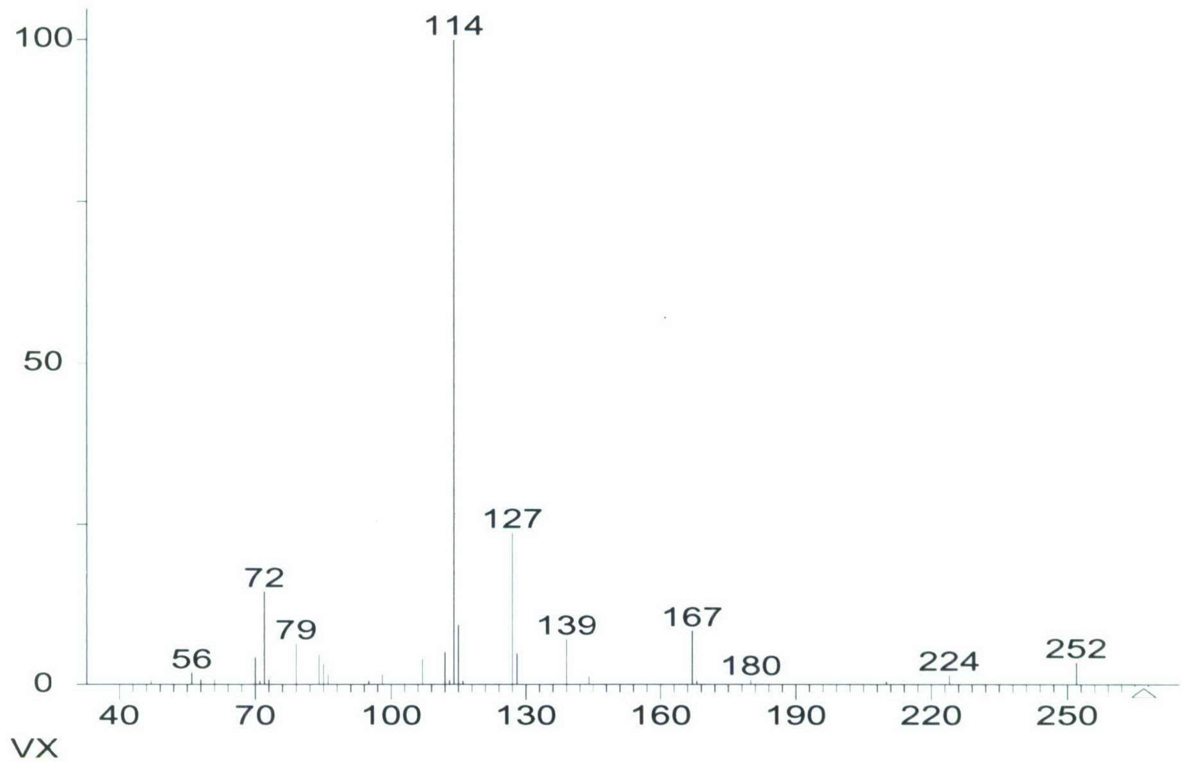
M/z	Proposed Structure
72	$H_2C{=}\overset{+}{N}H{-}iPr$
70	$H_2C{=}CH{-}\overset{+}{N}(H){=}CHCH_3$
69	$[C_4H_7N]^{+\cdot}$
61	
58	$iPrNH^+ \rightleftharpoons (H_3C)_2C{=}\overset{+}{N}H_2 \rightleftharpoons H_2C{=}C(CH_3){-}\overset{+}{N}H_3$
56	$[C_3H_6N]^+$
55	$[C_3H_5N]^{+\cdot}$
47	$^+P{=}O \longleftrightarrow P{\equiv}O^+$
44	
43	$H\overset{+}{C}(CH_3)_2$
42	$\overset{+}{C}H_2\text{-}CH{=}NH \longleftrightarrow CH_2{=}CH\text{-}NH^+$
30	$H_2C{=}\overset{+}{N}H_2$
28	$HC{\equiv}NH^+$



Scheme. Proposed Mass Spectral Fragmentation Pathways for VX

4. CONCLUSIONS

Tandem MS product ion spectra are provided for 20 VX fragment ions. Based on these spectra, proposed ion structures and pathways for VX fragmentation are provided. Spectra obtained for d5-VX provide support for the identifications and in particular provide conclusive evidence that the m/z 139 ion formed is the cyclic sulfonium ion resulting from loss of ethylene from the O-ethyl moiety rather than loss from the sulfonium ion moiety. The MS/MS product ion spectra are provided here as tools for the detection of VX trace levels in environmental samples and other complex matrices.



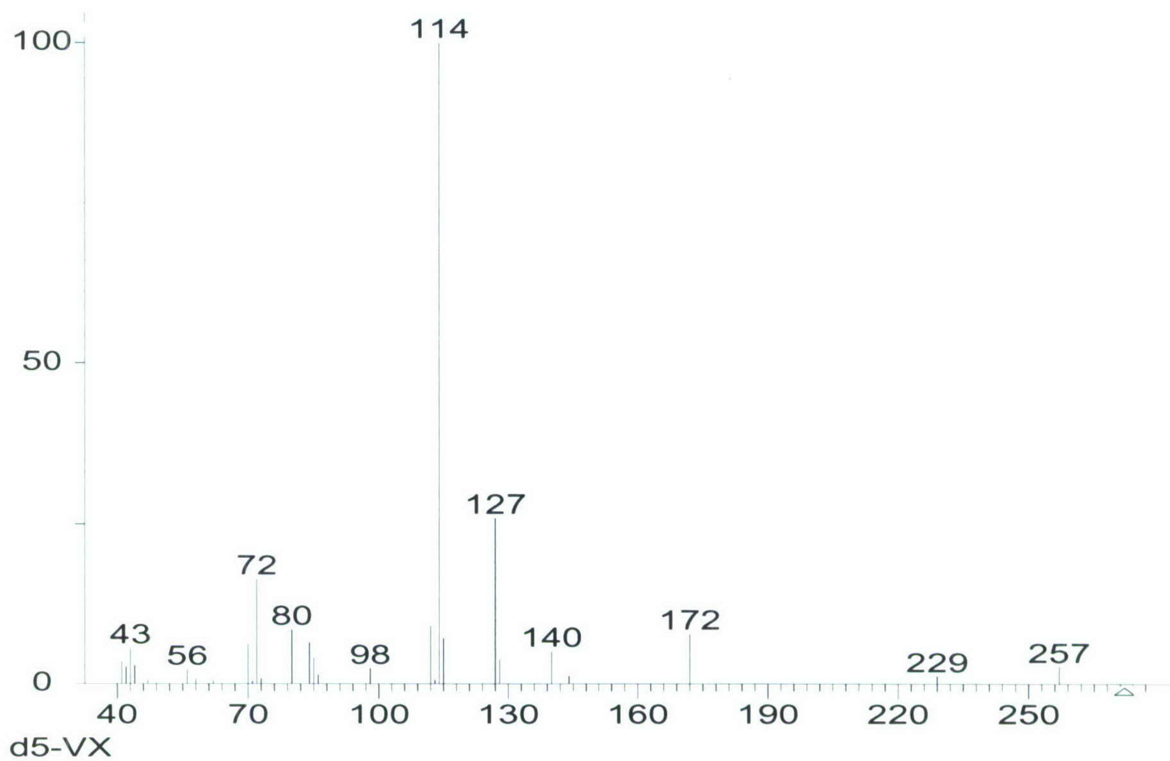


Figure 1. EI Mass Spectra of VX and d_5-VX

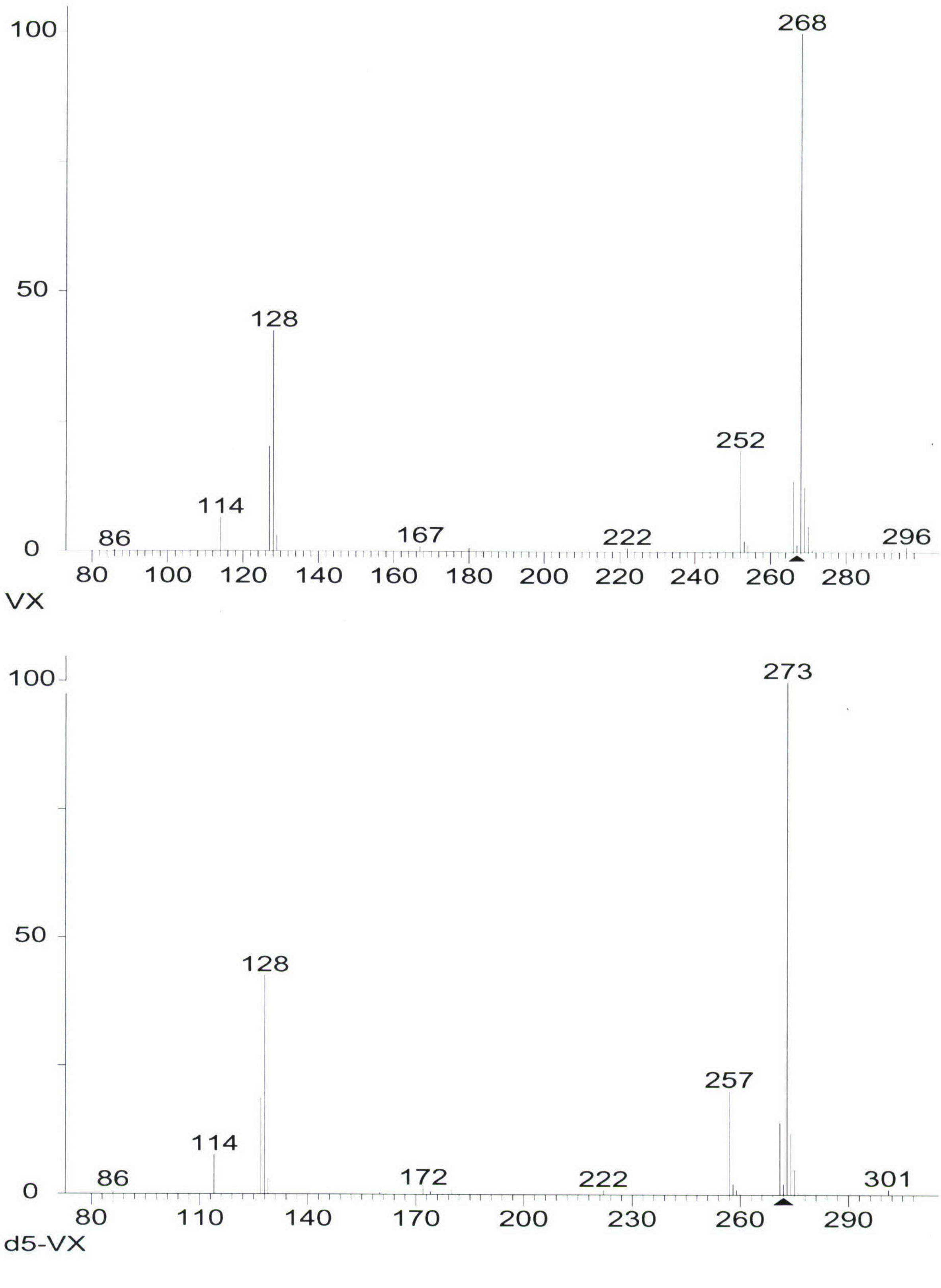


Figure 2. Methane CI Mass Spectra of VX and d_5-VX

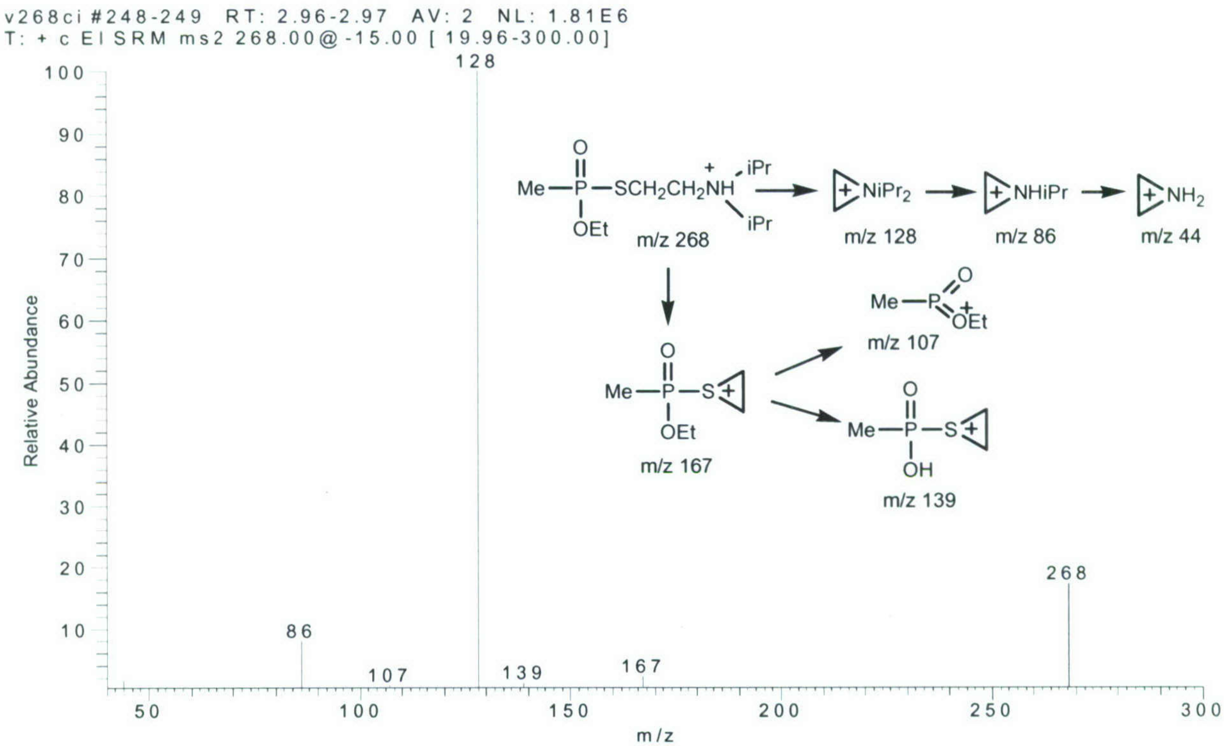


Figure 3. Product Ion Mass Spectrum of VX m/z 268 (CI)

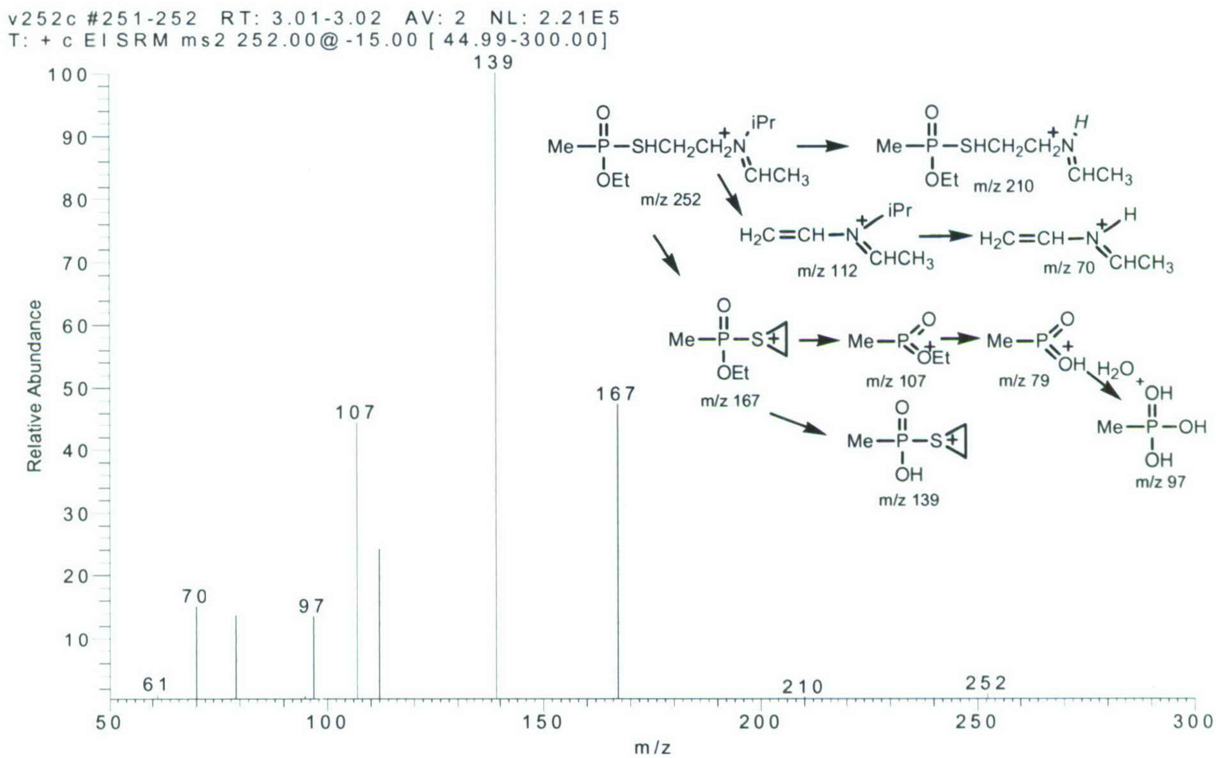


Figure 4. Product Ion Mass Spectrum of VX m/z 252 (EI)

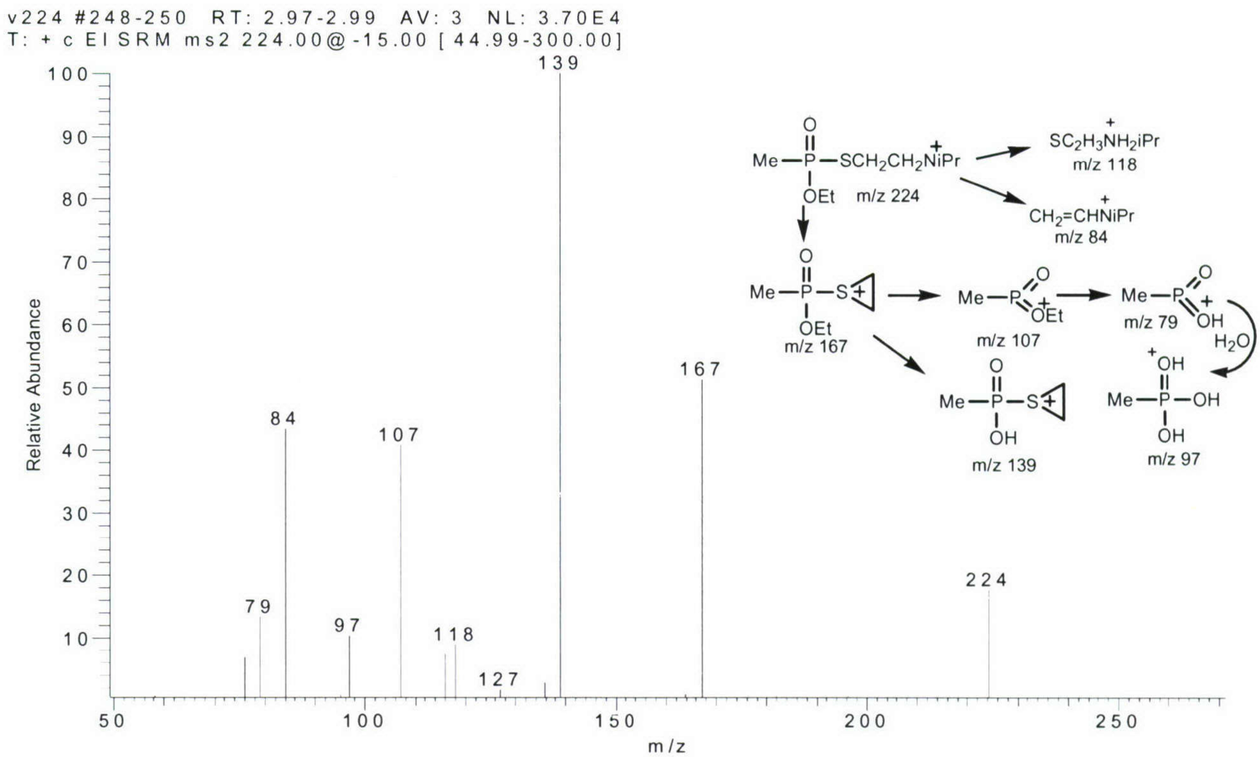


Figure 5. Product Ion Mass Spectrum of VX m/z 224 (EI)

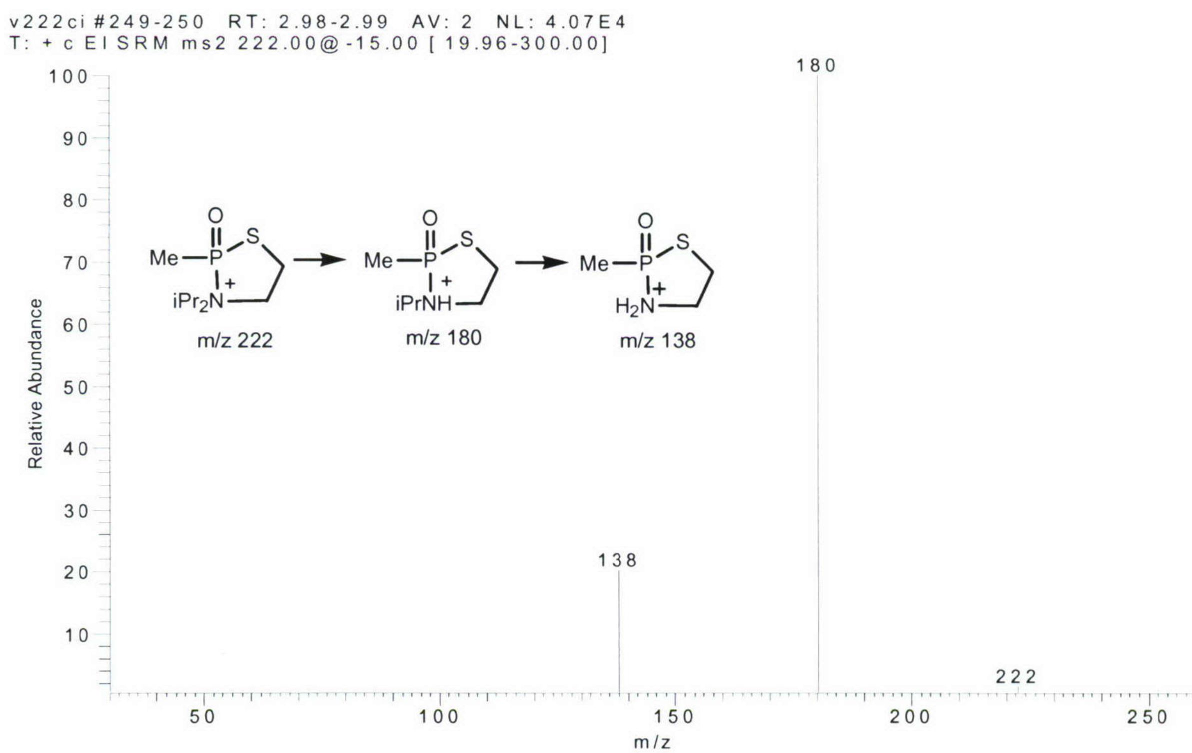


Figure 6. Product Ion Mass Spectrum of VX m/z 222 (CI)

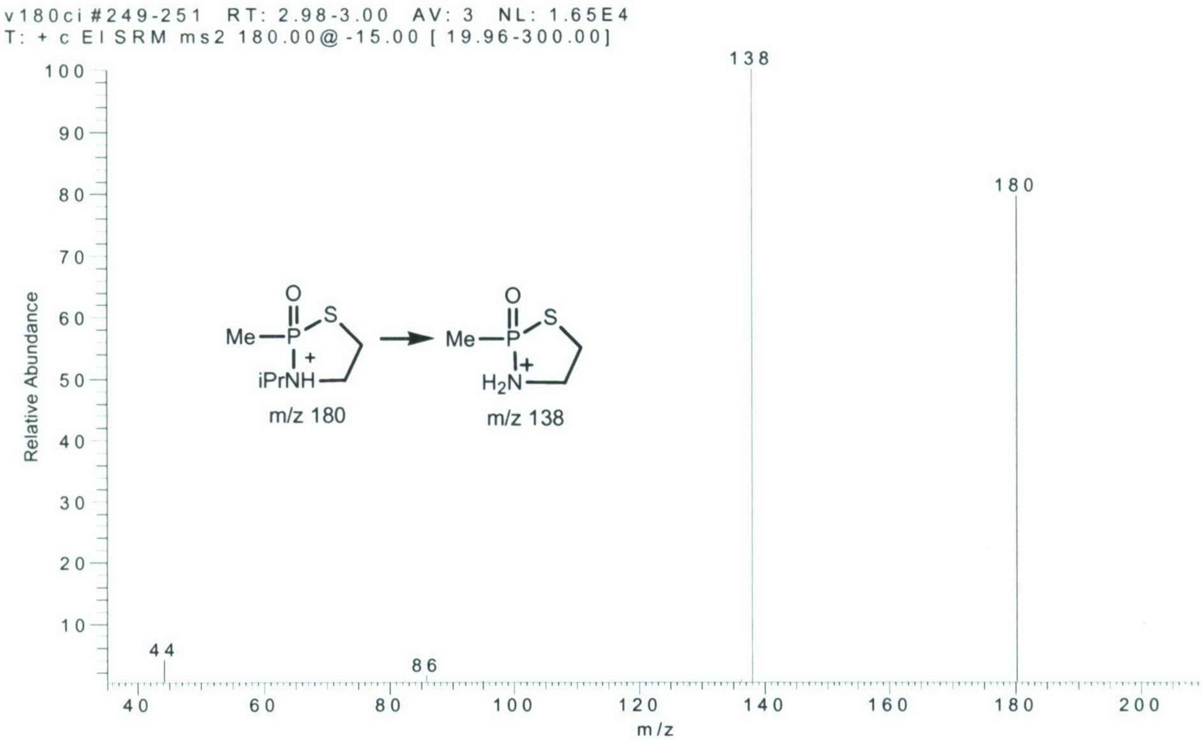


Figure 7. Product Ion Mass Spectrum of VX m/z 180 (EI)

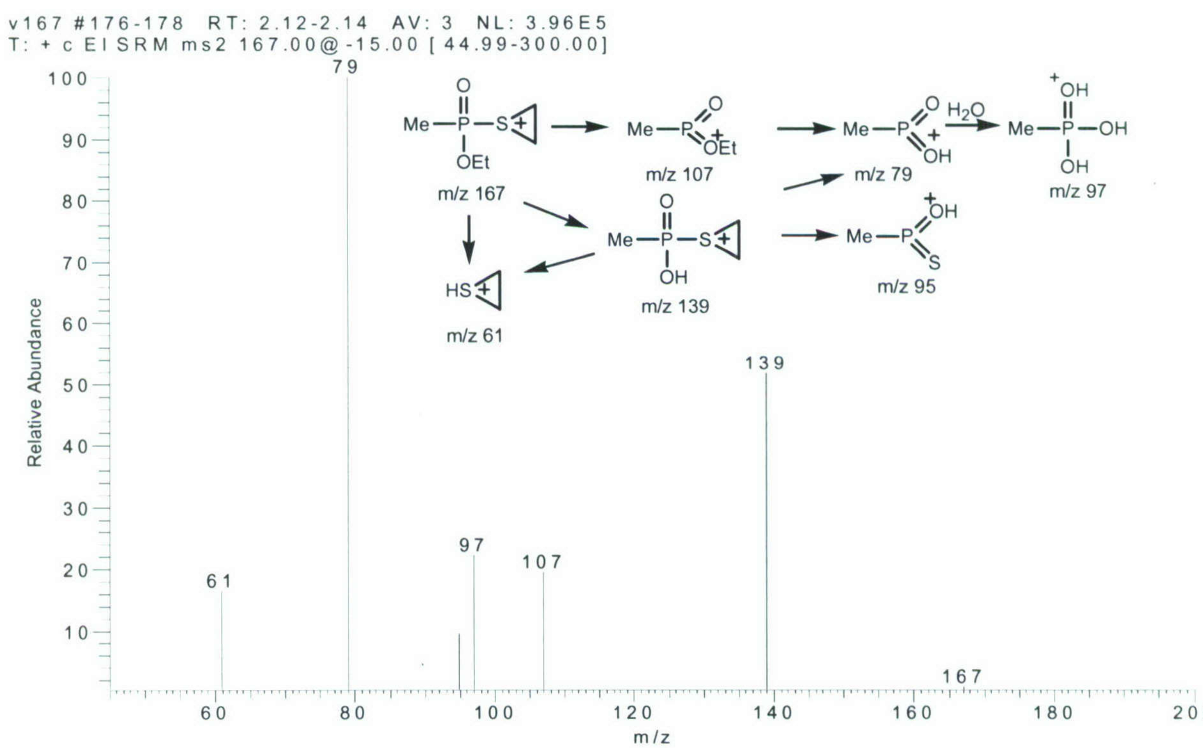


Figure 8. Product Ion Mass Spectrum of VX m/z 167 (EI)

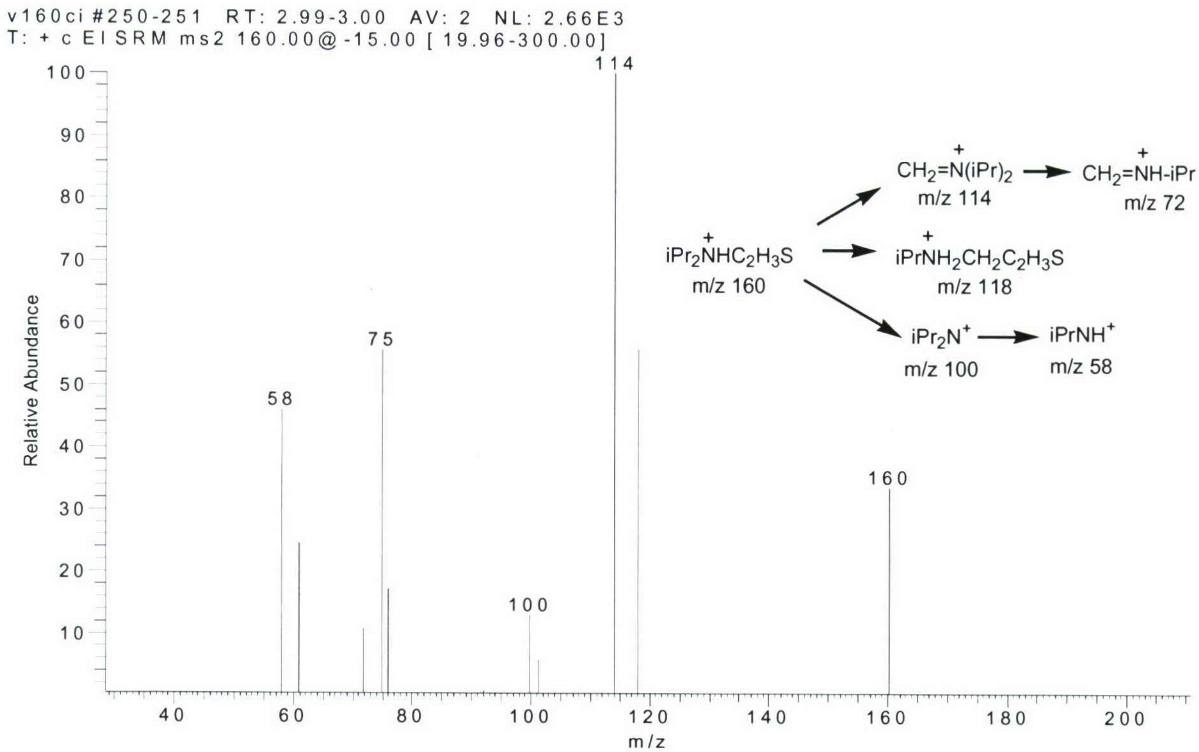


Figure 9. Product Ion Mass Spectrum of VX m/z 160 (CI)

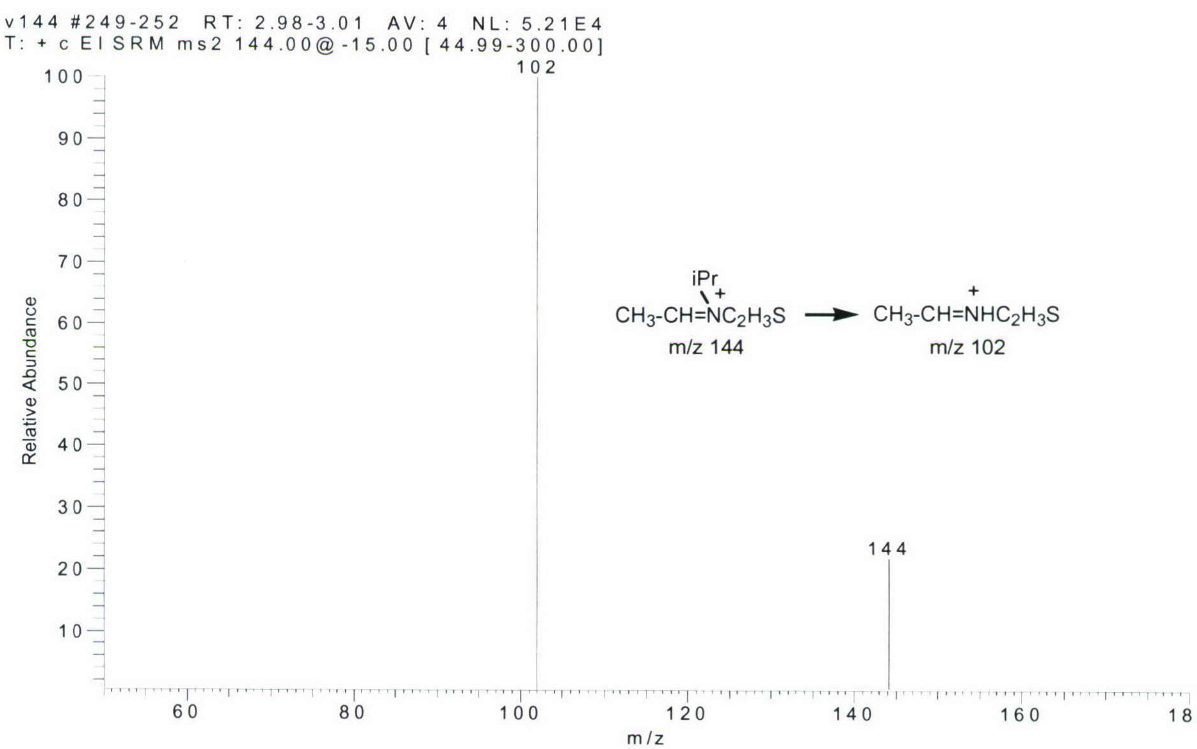


Figure 10. Product Ion Mass Spectrum of VX m/z 144 (EI)

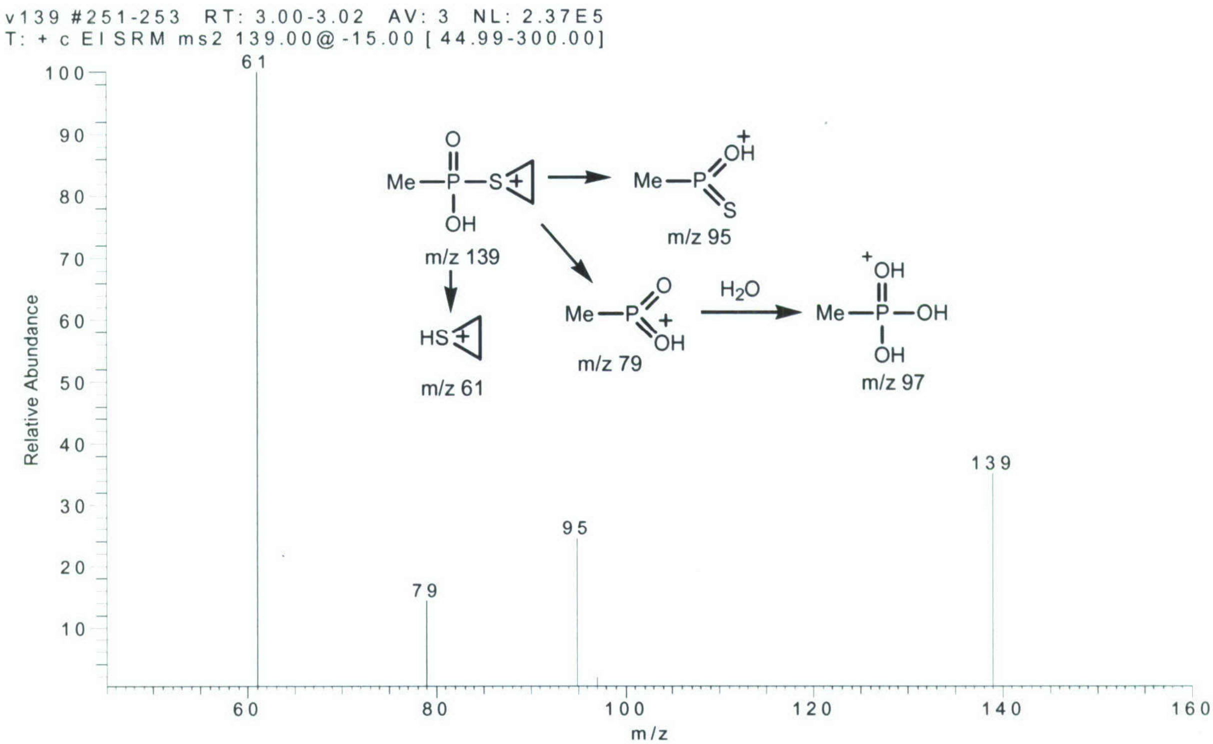


Figure 11. Product Ion Mass Spectrum of VX m/z 139 (EI)

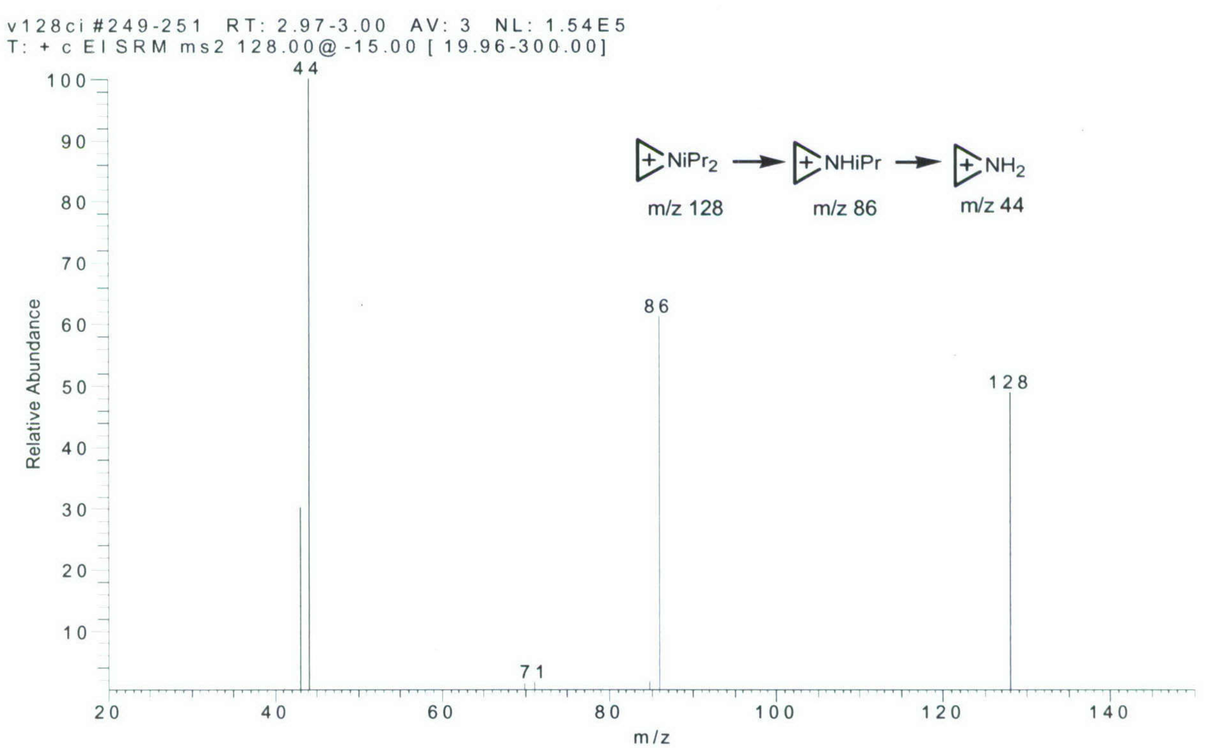


Figure 12. Product Ion Mass Spectrum of VX m/z 128 (CI)

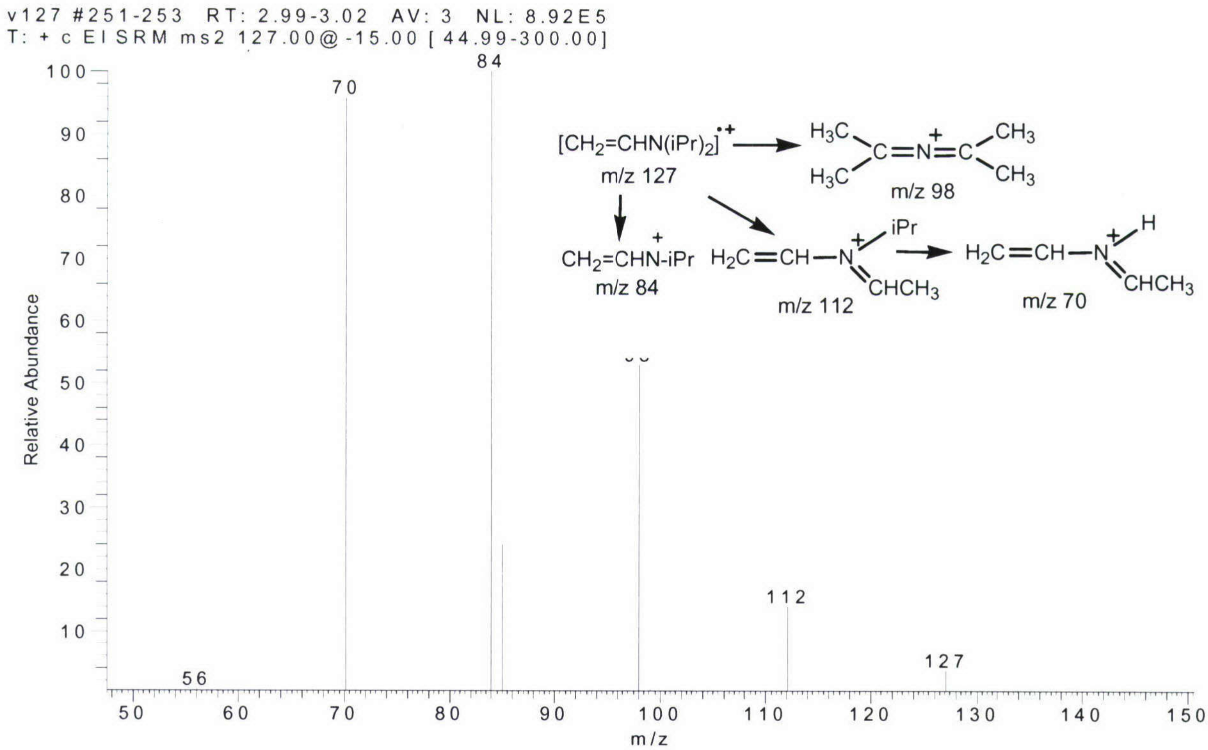


Figure 13. Product Ion Mass Spectrum of VX m/z 127 (EI)

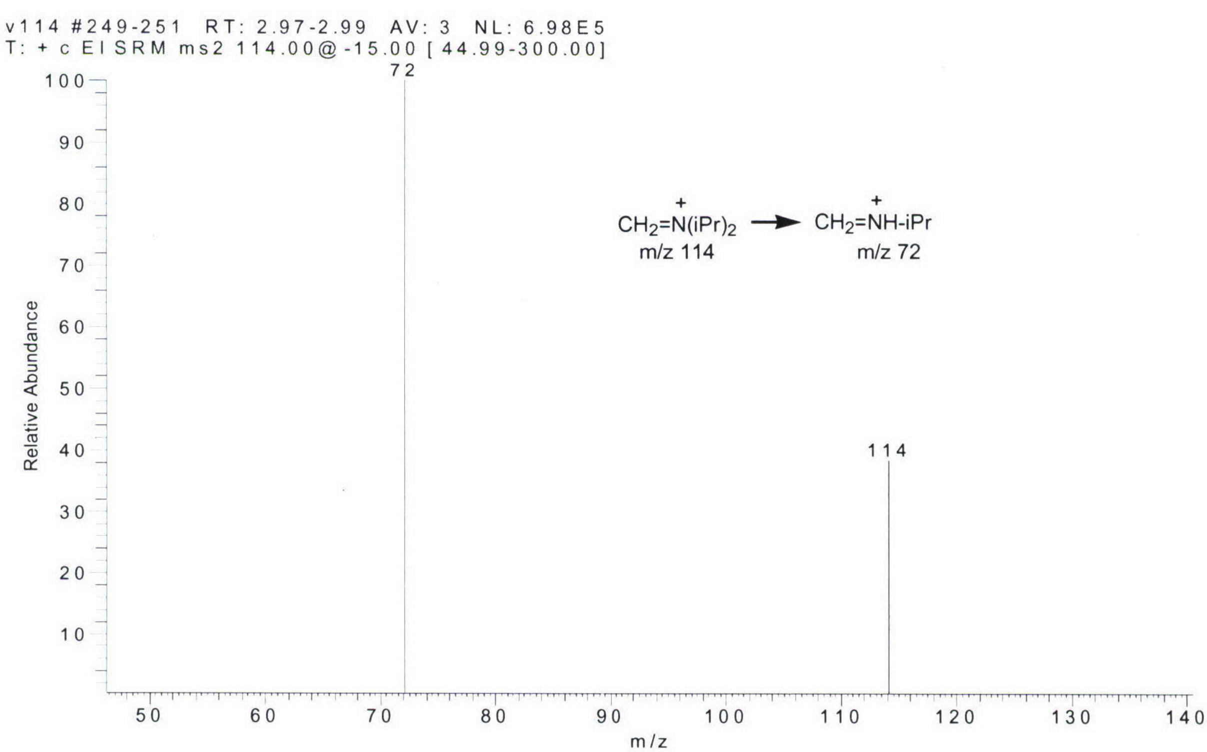


Figure 14. Product Ion Mass Spectrum of VX m/z 114 (EI)

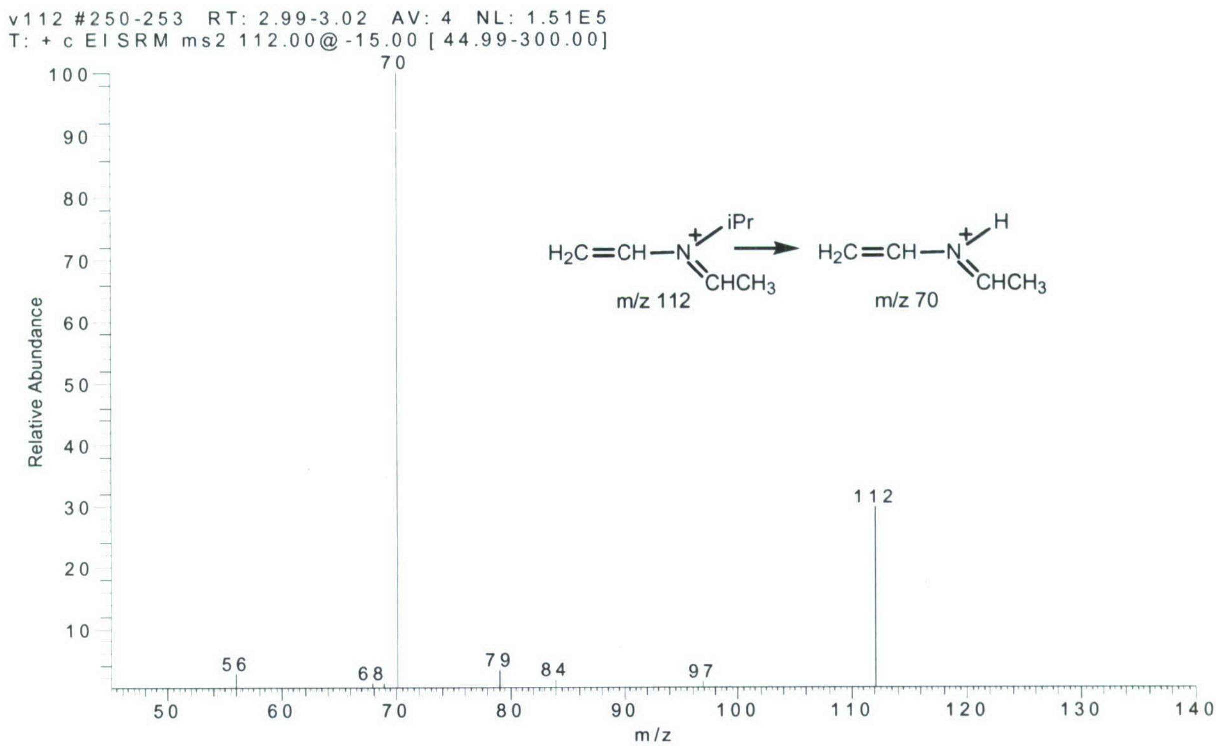


Figure 15. Product Ion Mass Spectrum of VX m/z 112 (EI)

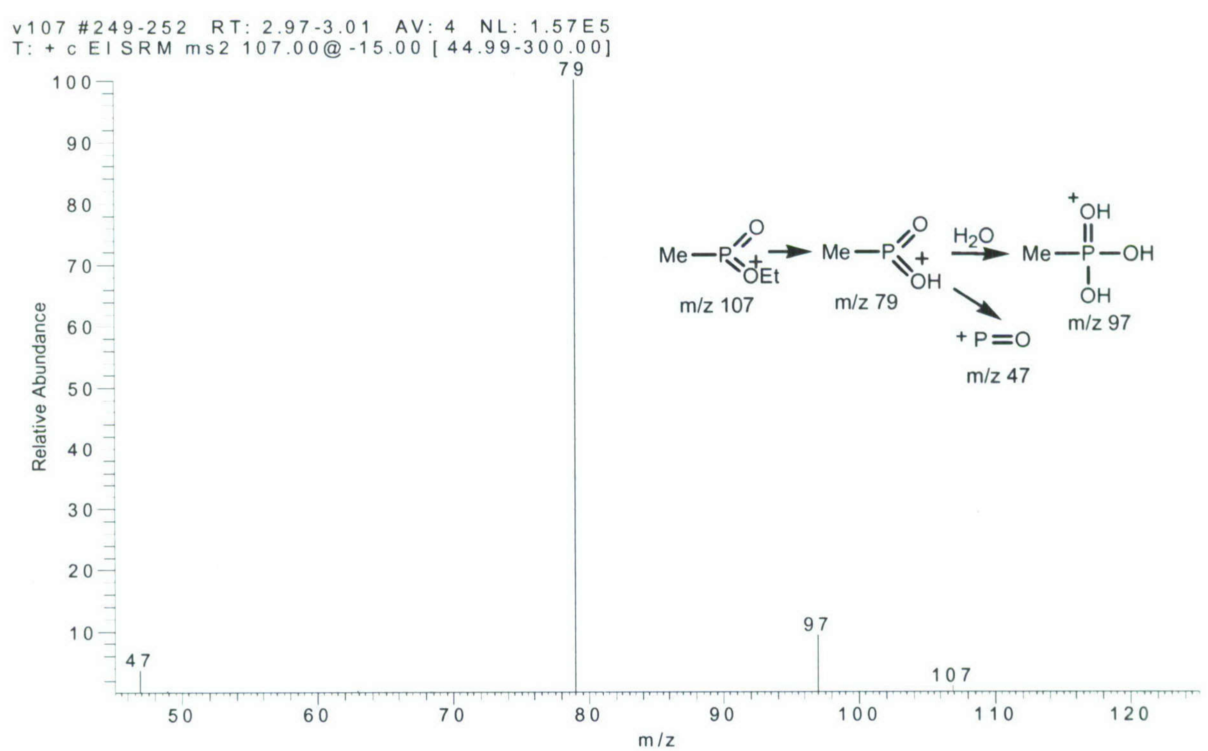


Figure 16. Product Ion Mass Spectrum of VX m/z 107 (EI)

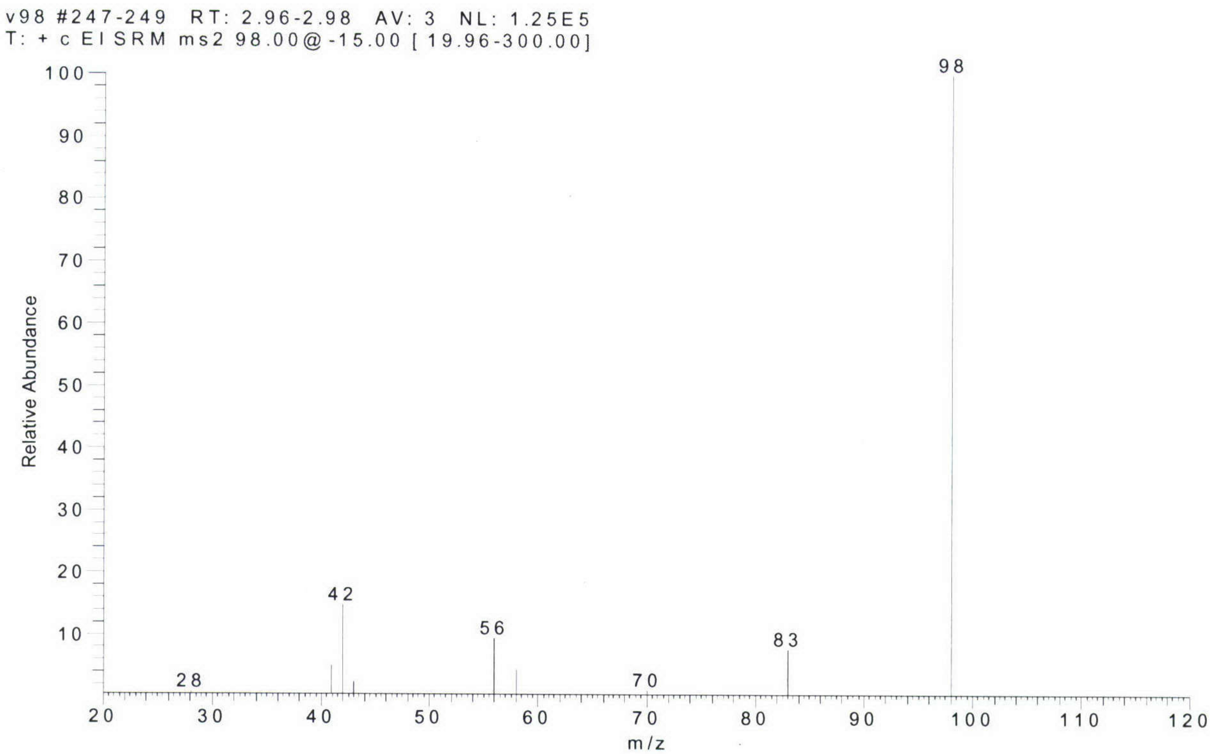


Figure 17. Product Ion Mass Spectrum of VX m/z 98 (EI)

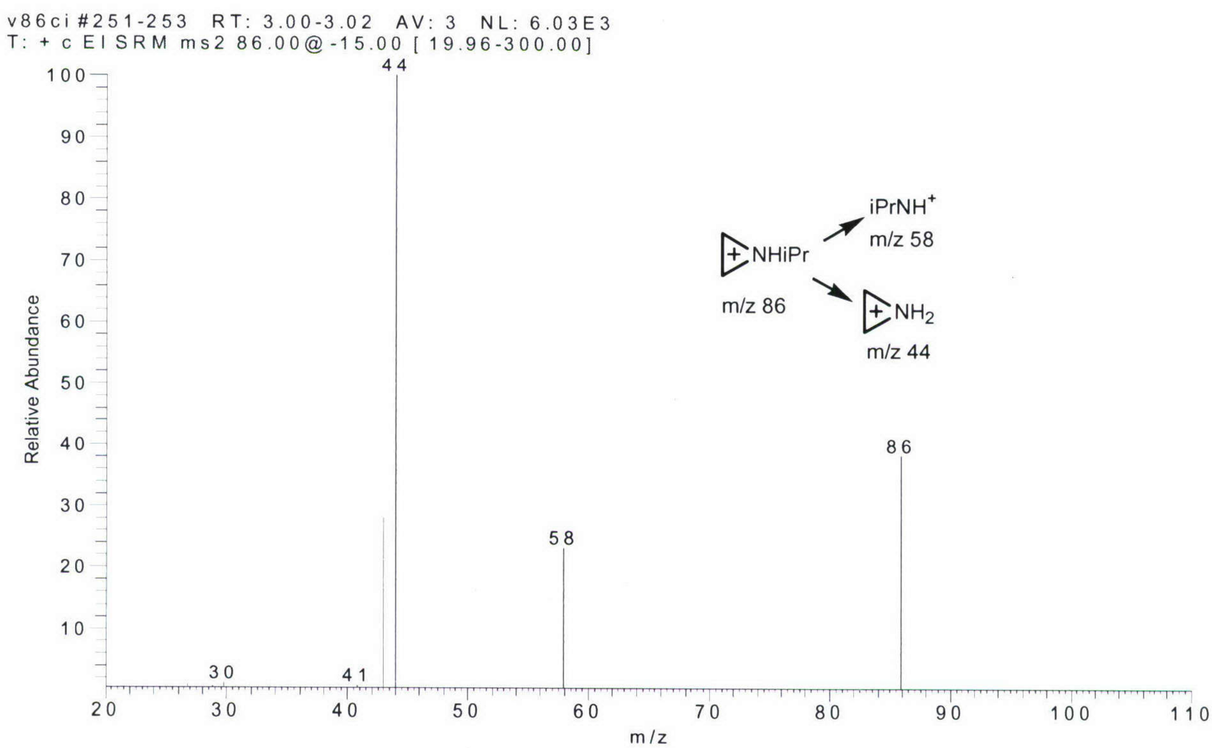


Figure 18. Product Ion Mass Spectrum of VX m/z 86 (CI)

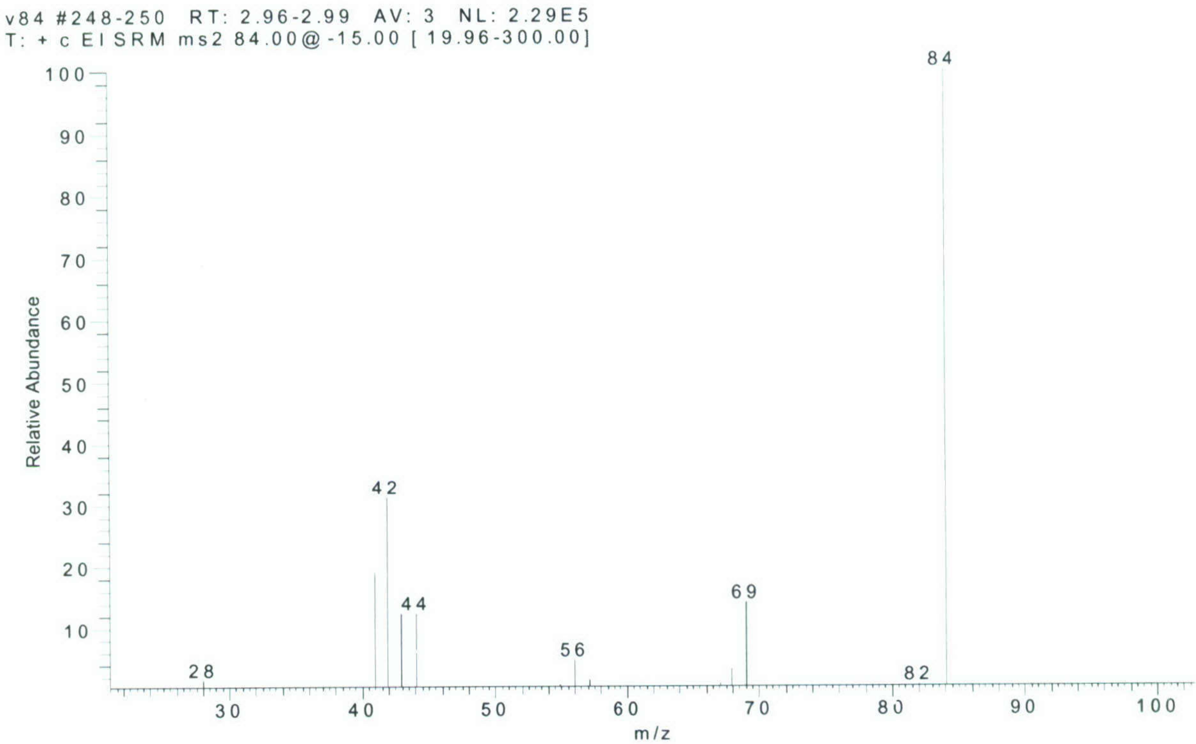


Figure 19. Product Ion Mass Spectrum of VX m/z 84 (EI)

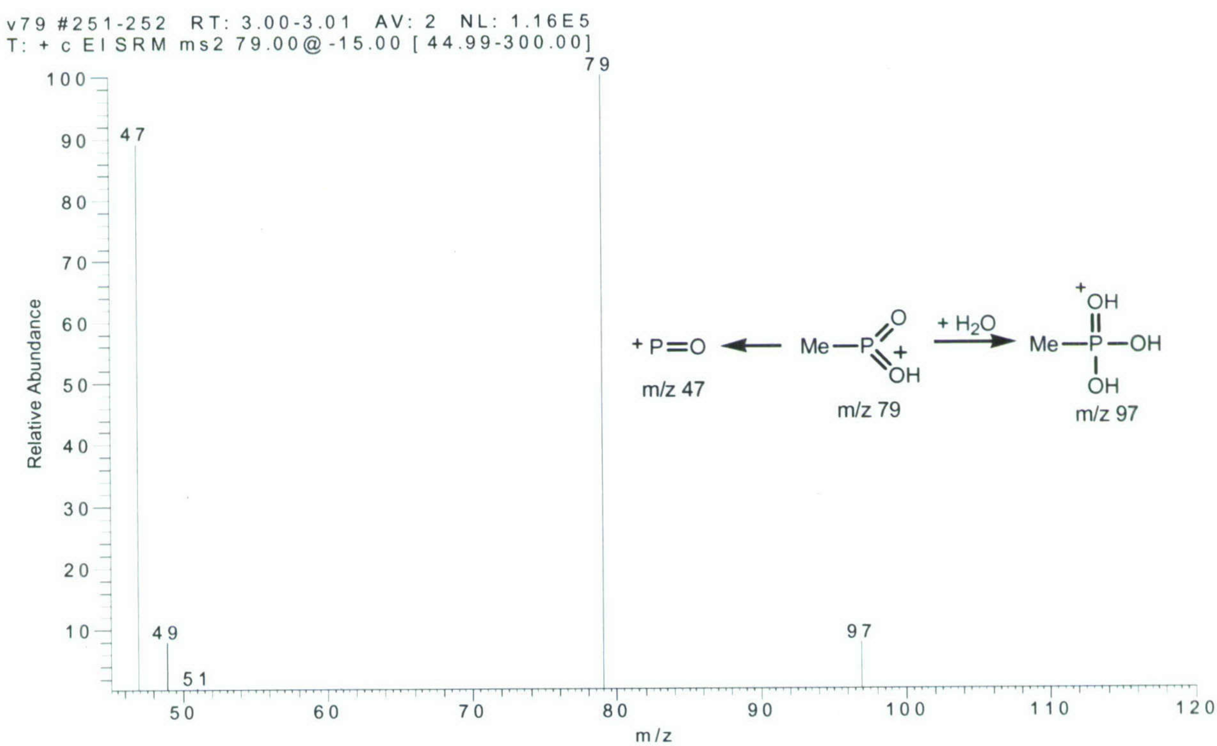


Figure 20. Product Ion Mass Spectrum of VX m/z 79 (EI)

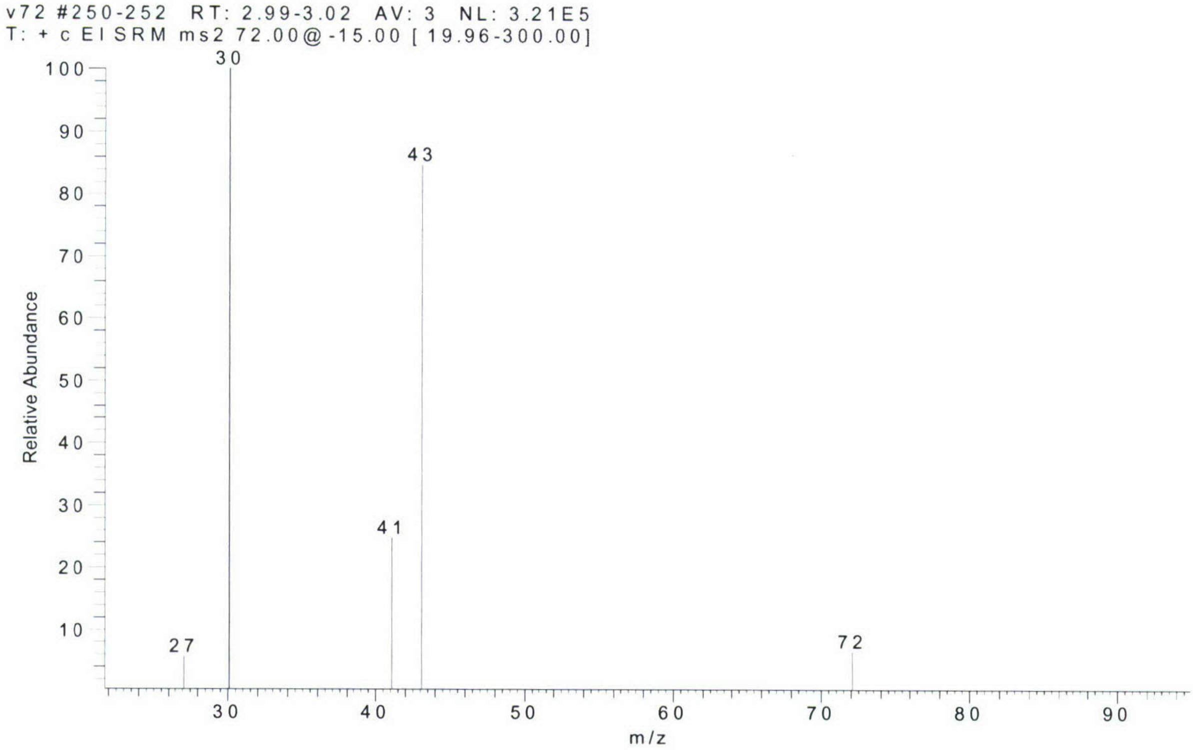


Figure 21. Product Ion Mass Spectrum of VX m/z 72 (EI)

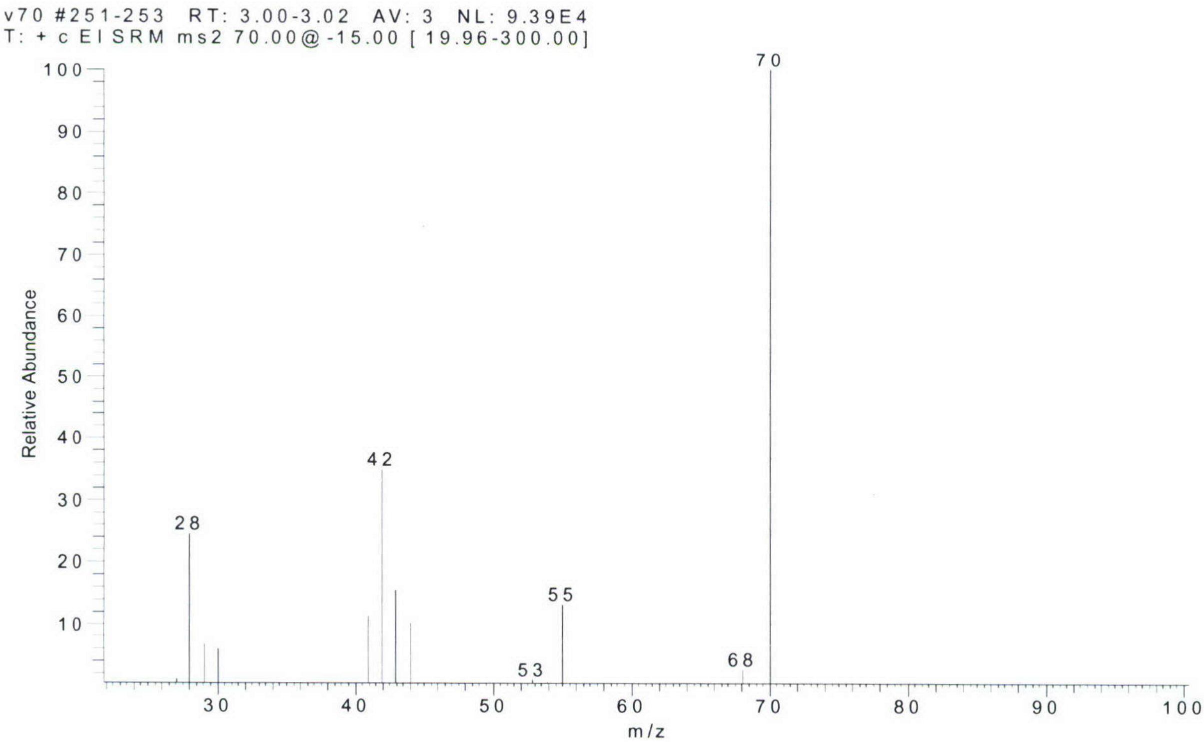


Figure 22. Product Ion Mass Spectrum of VX m/z 70 (EI)

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